Direct Diode Detection (3D),

Base-Band Q (BBQ) Measurement,

Some SPS and PS 2004 Results

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Outline

- Limitations of existing techniques
- The Direct Diode Detection (3D) principle
- The Baseband Tune (BBQ) system
- CERN SPS and PS results
- Summary

Tune Measurement – Classical Approach

The classical approaches to tune measurement

- Single frequency detection:
  - – Sample pick-up data turn by turn
  - – Produce a difference signal
  - – Filter around a single revolution line
  - – Detect this frequency
- Homodyne detection:
  - – Sample pick-up data turn by turn
  - – Produce a sum and difference signal
  - – Mix the difference signal with the sum
    - moves the pick-up response into baseband
  - – Low pass filter & detect in baseband

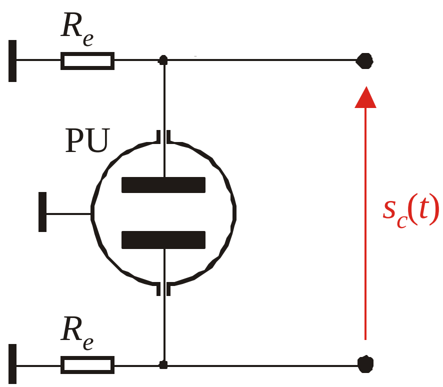
Tune Measurement – Classical Approach

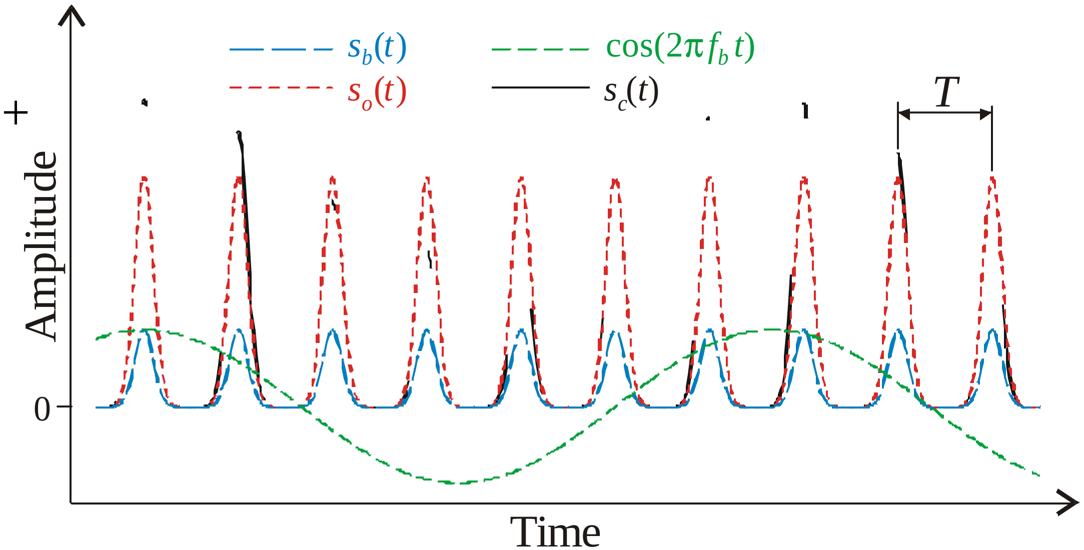
tune modulation modulation depth

$$s_c(t) = \cos(2p\, f_b\, t)\left(s_b(t) * \sum_{n=-\infty}^{\infty} d(t-nT) \right) +$$

$$+\ s_o(t) * \sum_{n=-\infty}^{\infty} d(t-nT)$$

Orbit offset

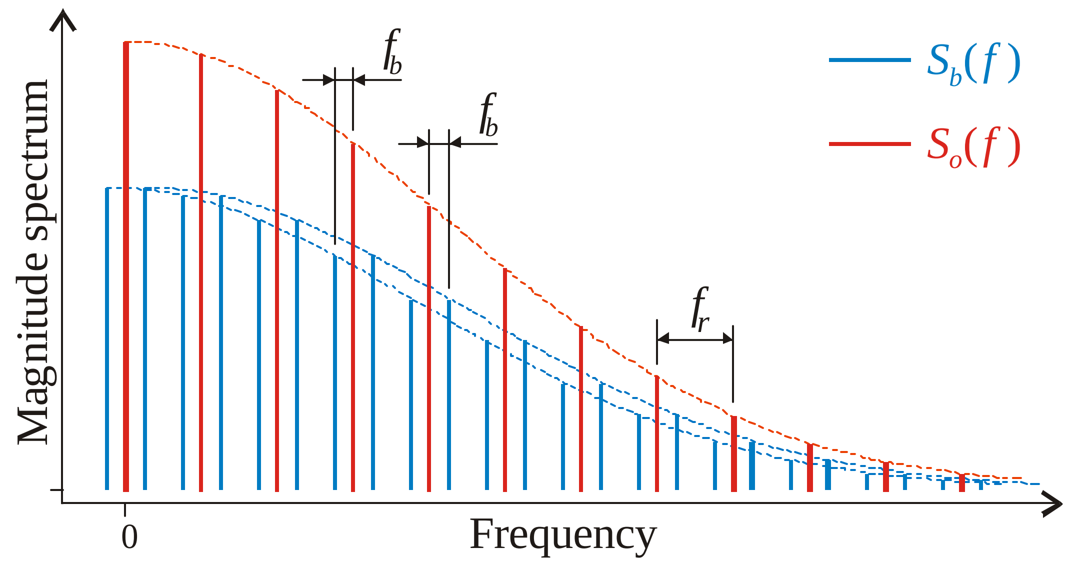




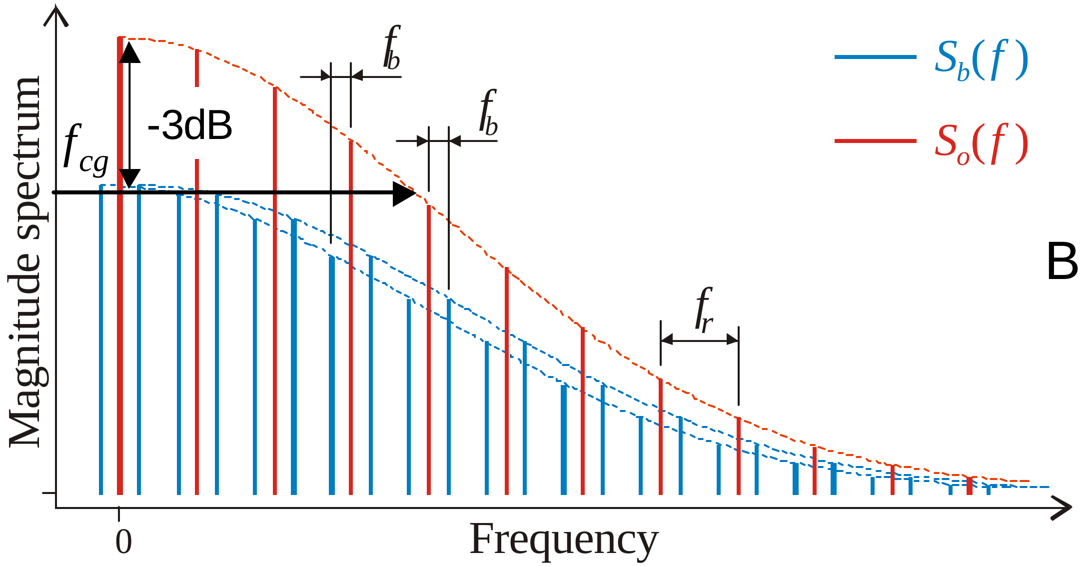
$$S_c(f) = \left| \frac{1}{2} S_b(f-f_b) \sum_{n=-\infty}^{\infty} d\left(f - f_b - \frac{n}{T} \right) + \right.$$

$$+ \frac{1}{2} S_b(f+f_b) \sum_{n=-\infty}^{\infty} d\left(f + f_b - \frac{n}{T} \right) +$$

$$\left. + S_o(f) \sum_{n=-\infty}^{\infty} d\left(f - \frac{n}{T} \right) \right|$$



Tune Measurement – Classical Approach



Bunch spectrum cut-off frequency

$$f_{cg} = \frac{\sqrt{\ln(2)}}{2\mathrm{p}s} \cong \frac{0.133}{s}$$

- LHC bunch length (4s) ~ 1 ns ⇒ bunch spectrum cut-off of ~ 500 MHz.

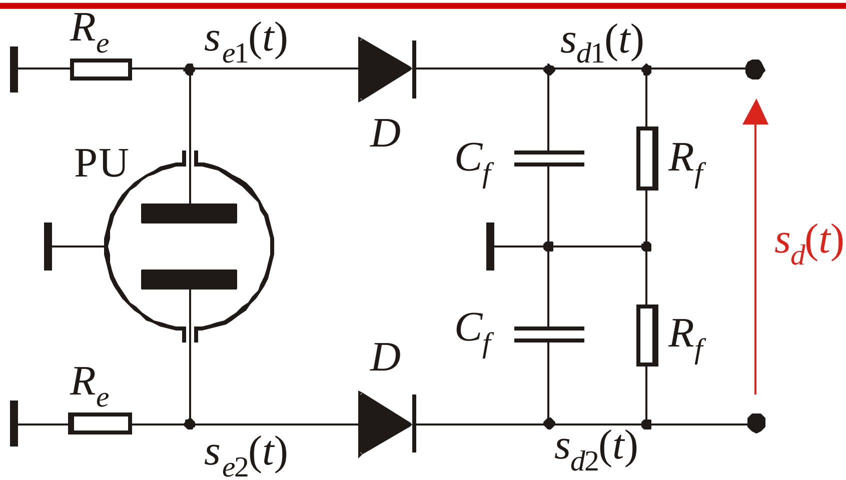
- For one bunch in the machine, the revolution lines are spaced by 11 kHz.
  - ~ 50 000 revolution lines & ~ 100 000 betatron lines within the bunch spectrum

- The classical “one line filtering method” looks at ~ 0.00001 of this spectral content.

Classical Tune Measurement – Limitations

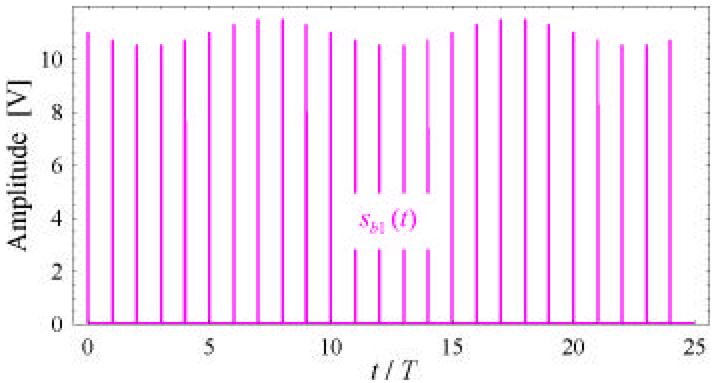
- Classical “one line filtering” looks at ~ 0.00001 of LHC spectral content
- Typical pick-up response is maximum in 100s MHz region
  - Use of high frequency electronics
- Requires dealing with very small signals in presence of large revolution lines
  - low noise amplifiers and mixers with limited dynamic ranges
  - saturation by huge revolution content.
- Resonant pick-up
  - Considerably improves response at the detection frequency
  - Enhancement not effective for single bunches
    - bunches do not pop-up in the PU often enough to maintain the resonance
  - Still requires low noise amplifiers and mixers
    - Saturation by revolution line remains a problem

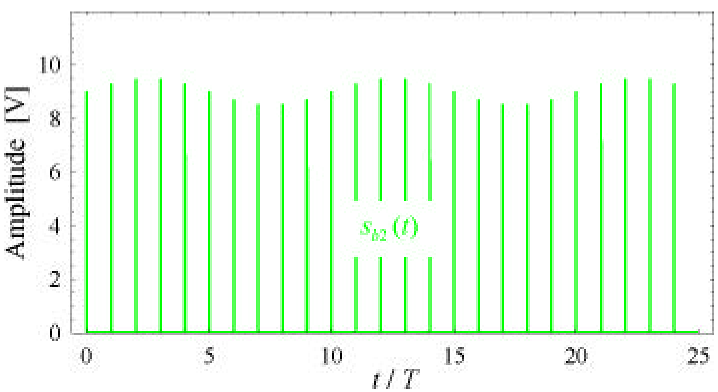
Direct Diode Detection – the Principle

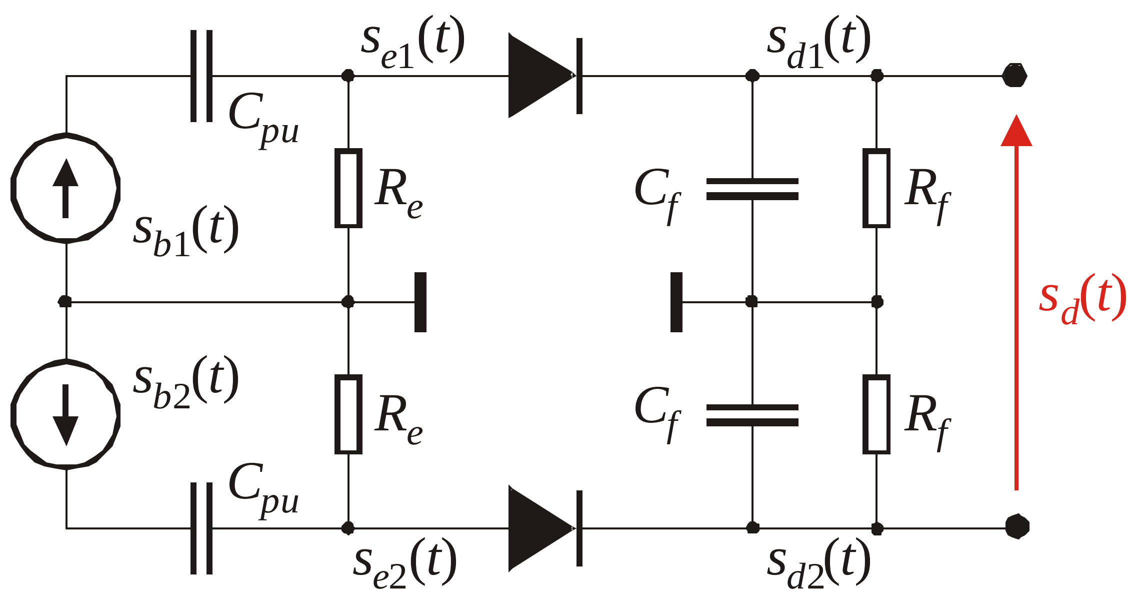


$$s_{b1}(t) = s_b(t)\,(1 + a)\big(1 + b\cos(2p\, f_b\, t)\big)$$
$$s_{b2}(t) = s_b(t)\,(1 - a)\big(1 - b\cos(2p\, f_b\, t)\big)$$

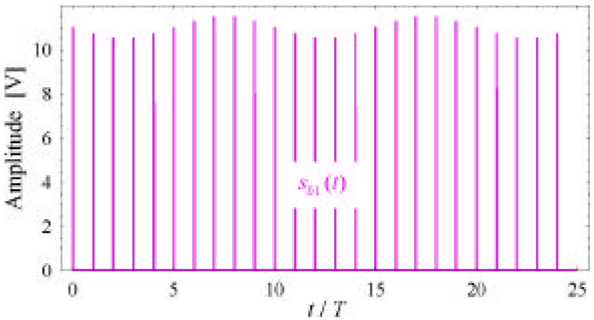
beam offset $a = 0.1$
betatron oscillation amp. $b = 0.05$
simulated tune value $q = 0.1$

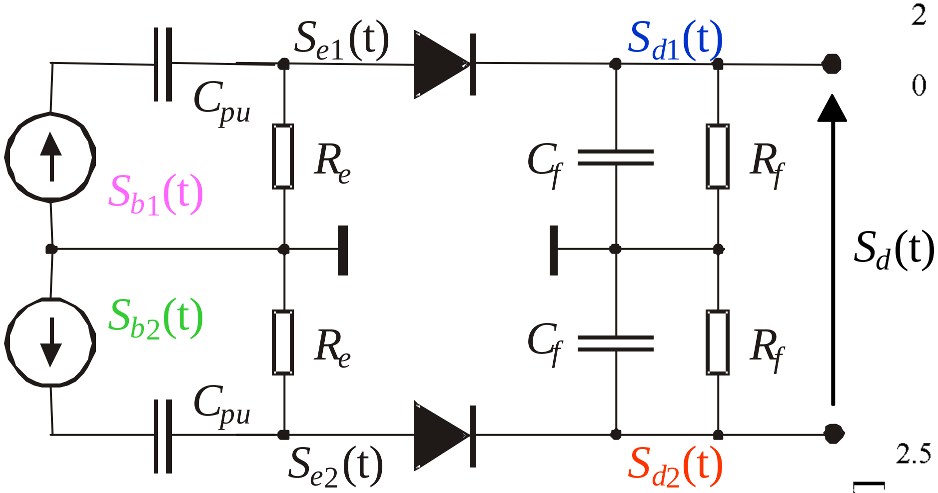


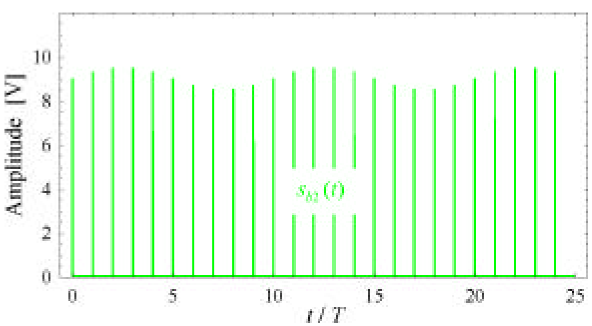


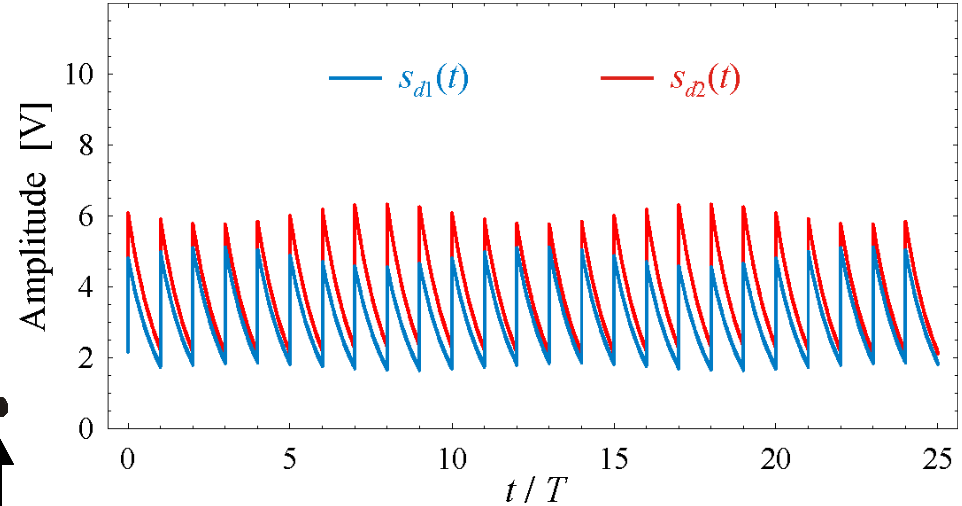


Direct Diode Detection – the Principle



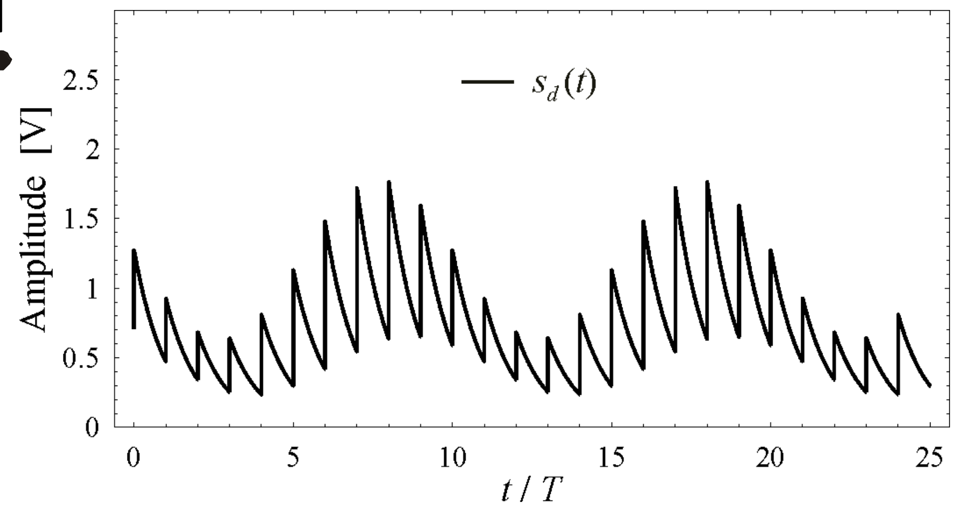


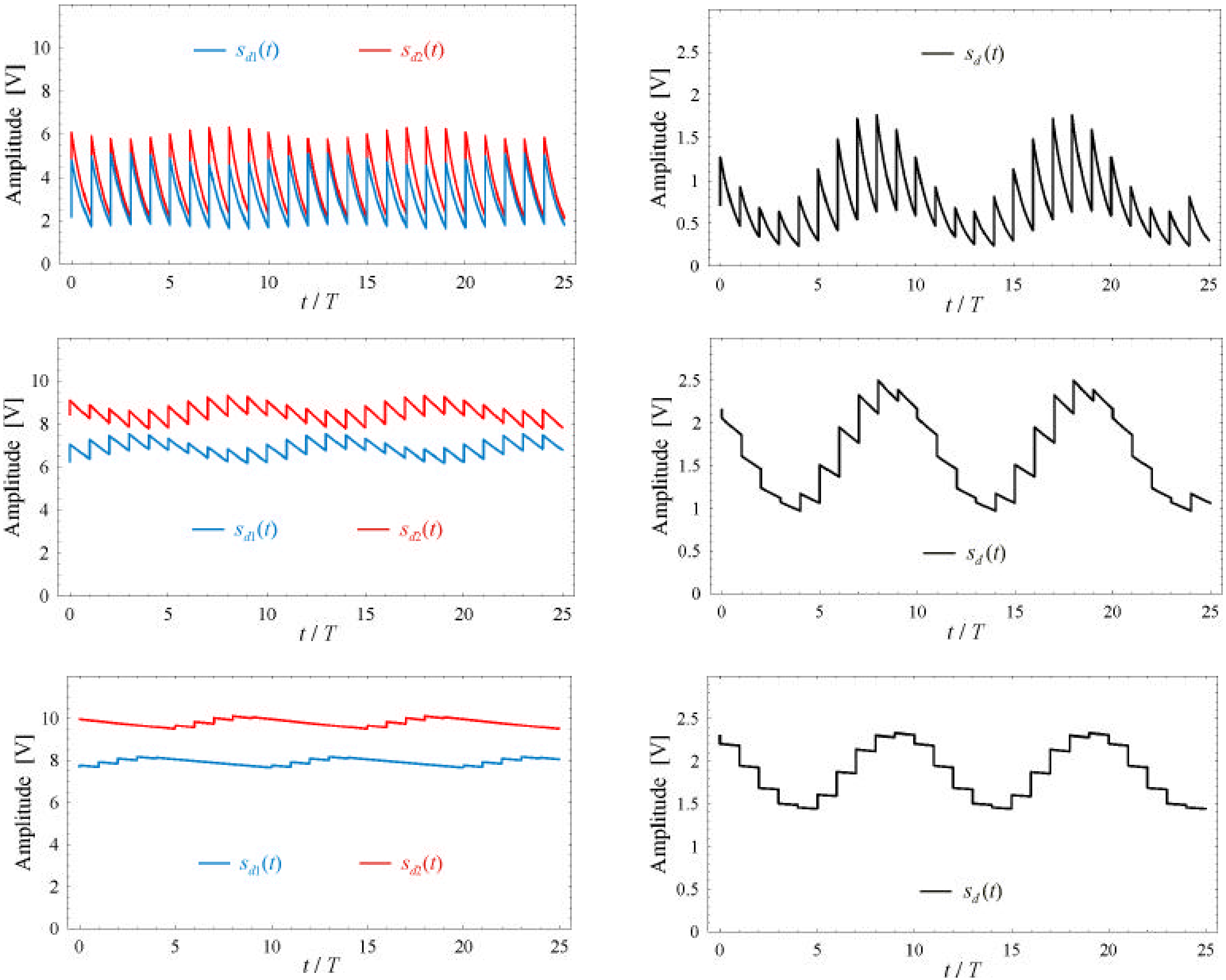




filter time constant $t = T$

storage capacitor $C_f = C_{pu}$

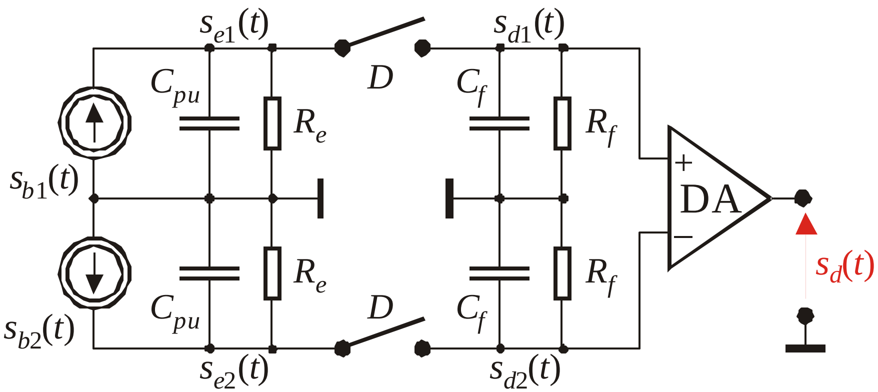




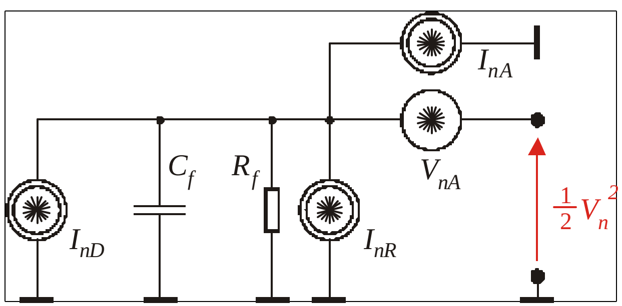
$t = T$

$t = 10\,T$

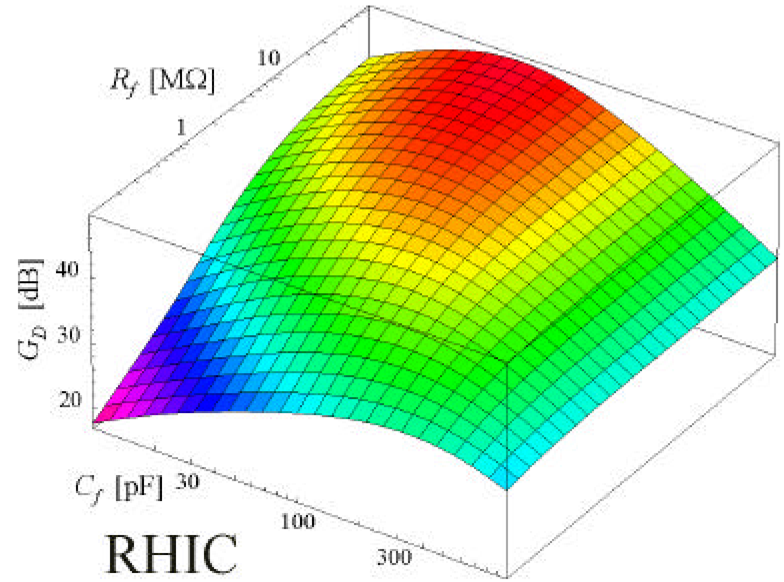
$t = 100\,T$



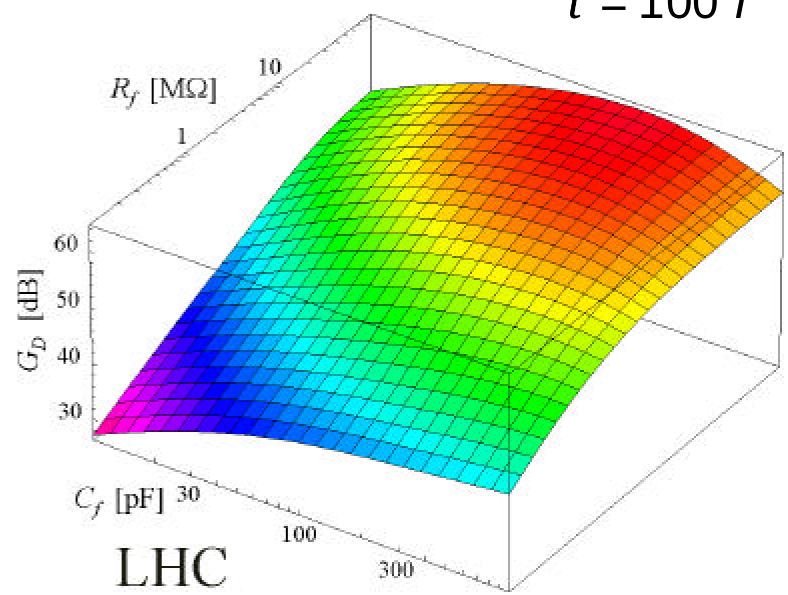
$$G_S = \frac{T}{\sqrt{2p s}} \cdot \frac{C_{pu}}{C_{pu}+C_f} \cdot \left| \frac{t\left(1-\exp\left(-j2p q - T/t\right)\right)}{1+j2p q} \right|$$



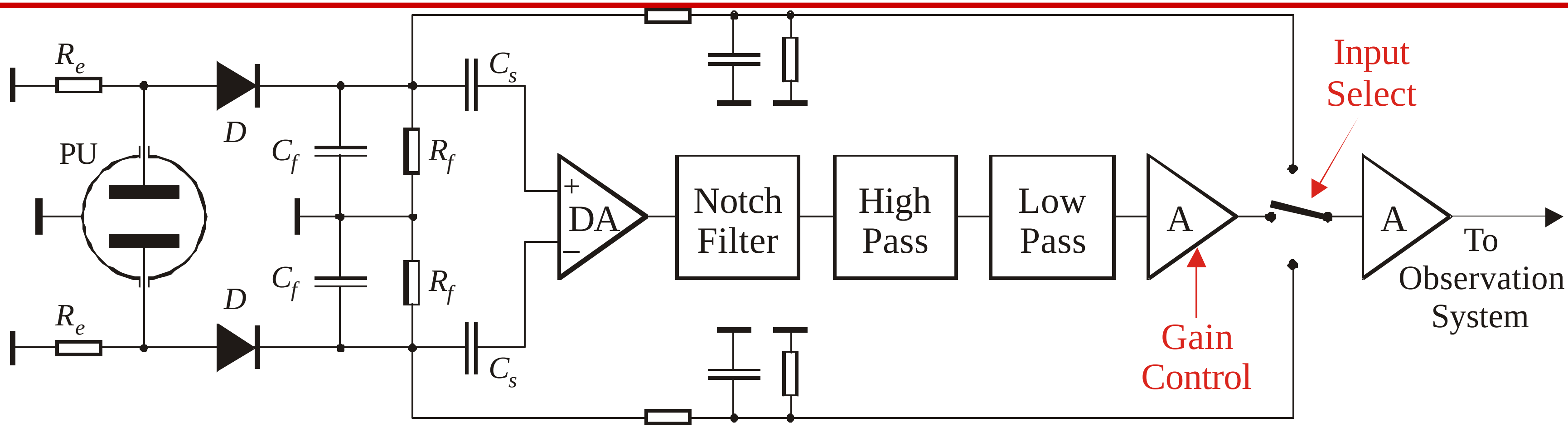
$$G_D = \frac{\dfrac{V_{nC}\,T}{\sqrt{p s}} \cdot \dfrac{R_f C_f C_{pu}}{C_{pu}+C_f} \left| \dfrac{1-\exp\left(-j2p q - T(R_f C_f)^{-2}\right)}{1+j2p q} \right|}{\sqrt{V_{nA}^2 + \dfrac{T^2 R_f^2 \left(2eI_{RD} + \dfrac{4k\Theta}{R_f} + I_{nA}^2\right)}{T^2 + (2p q R_f C_f)^2}}}$$



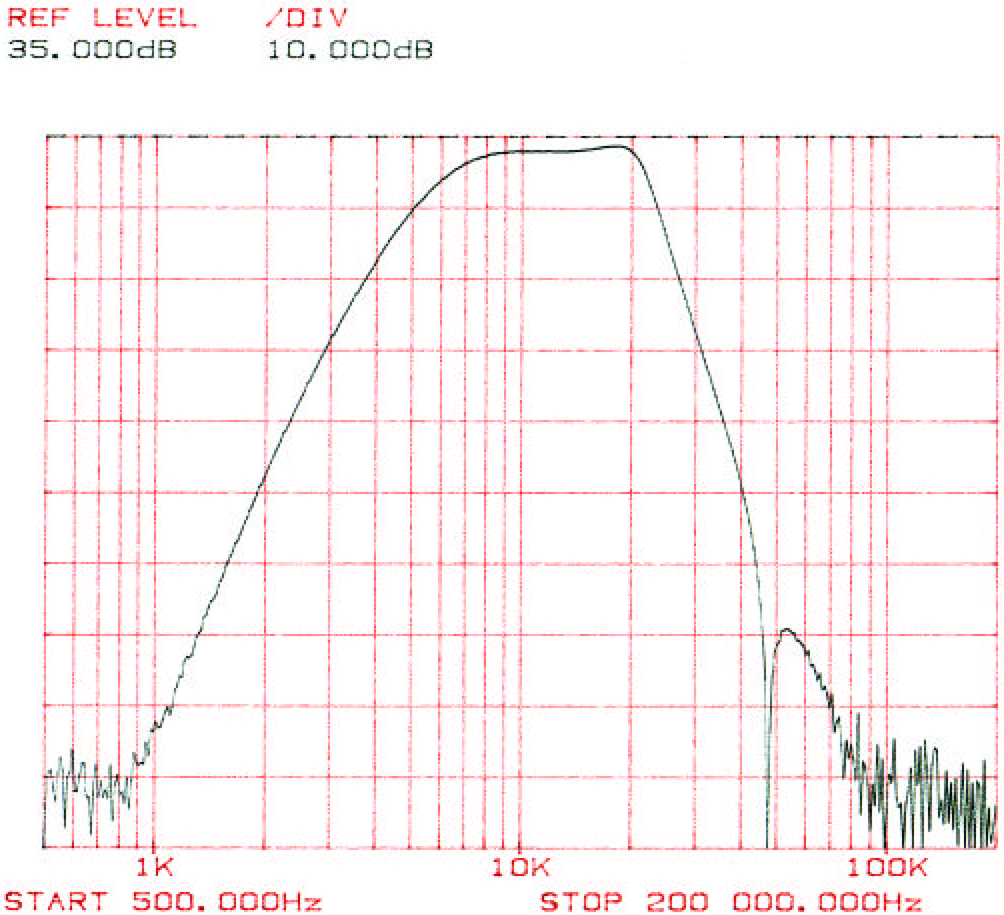
$t = 100\,T$

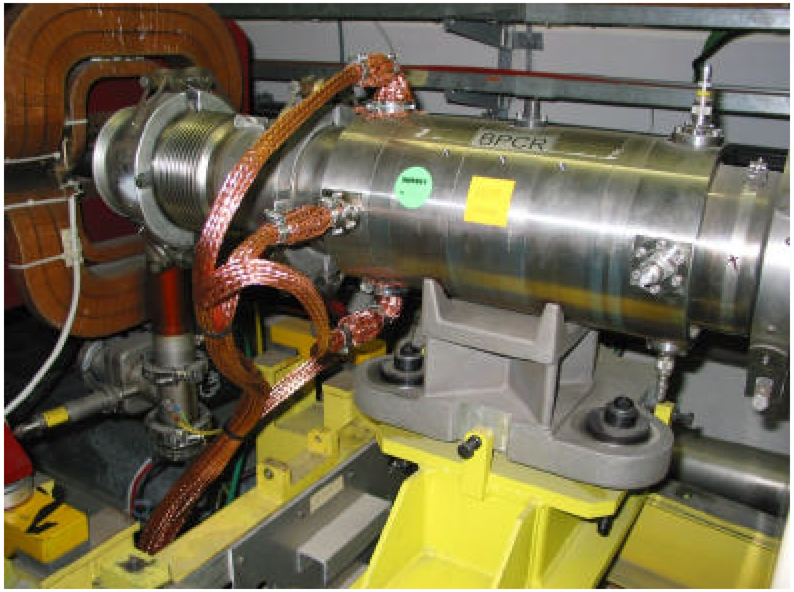


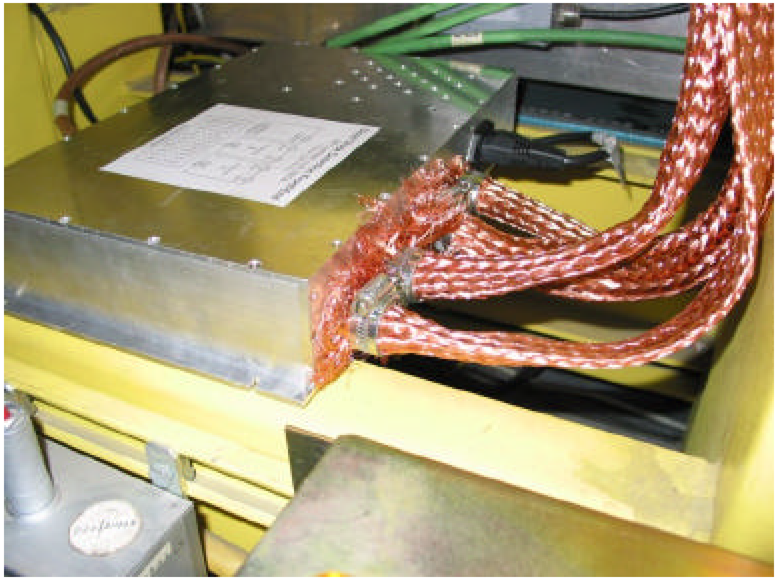
BBQ Architecture



BBQ Architecture





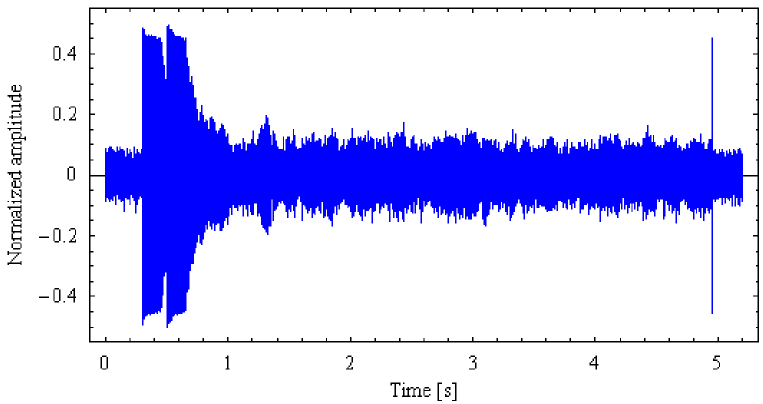


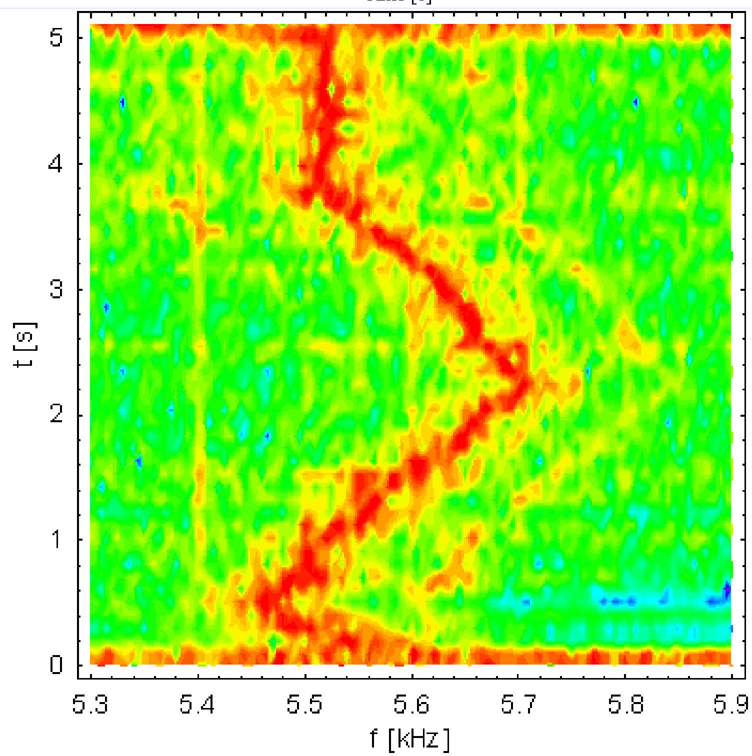
- Revolution frequency is attenuated by some 100 dB over an octave ($f_r/2$ is still within the bandwidth)
- The dynamic range of the first amplifier is some 15 V

SPS BBQ Measurements – Transverse Damper Noise

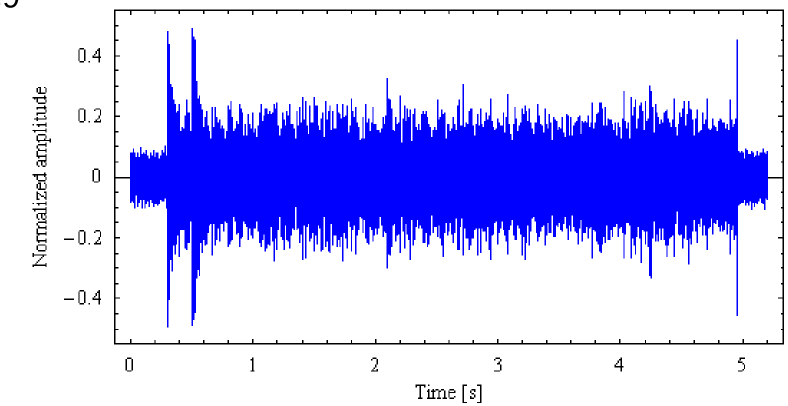
One LHC pilot bunch, intensity ca 5e9

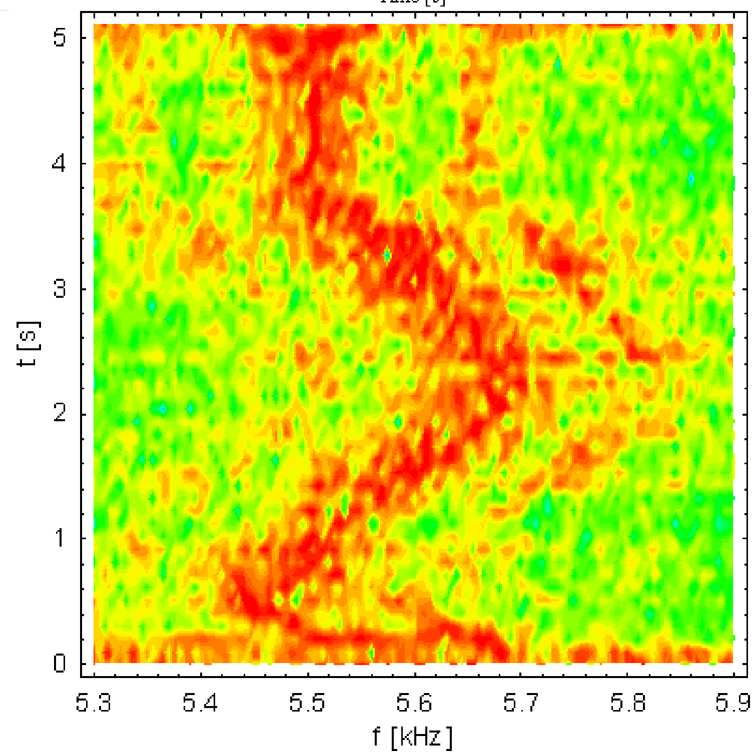
Damper system OFF



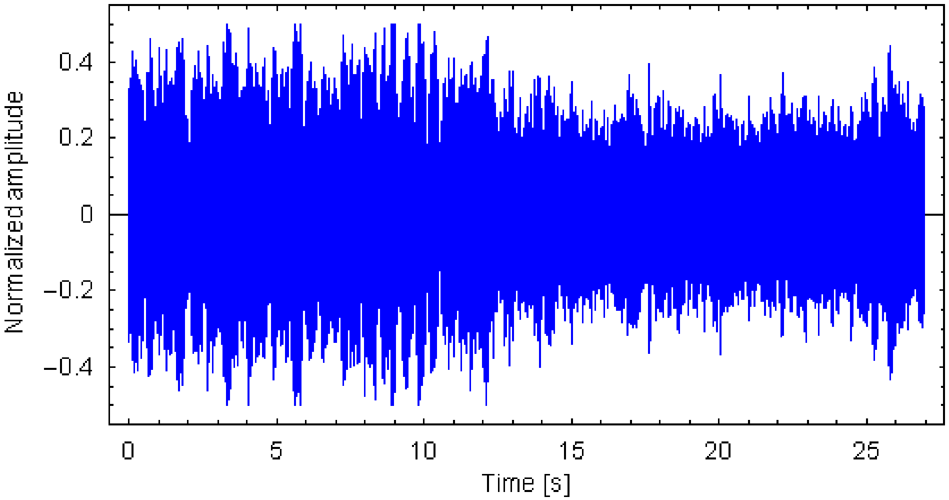


Damper system ON



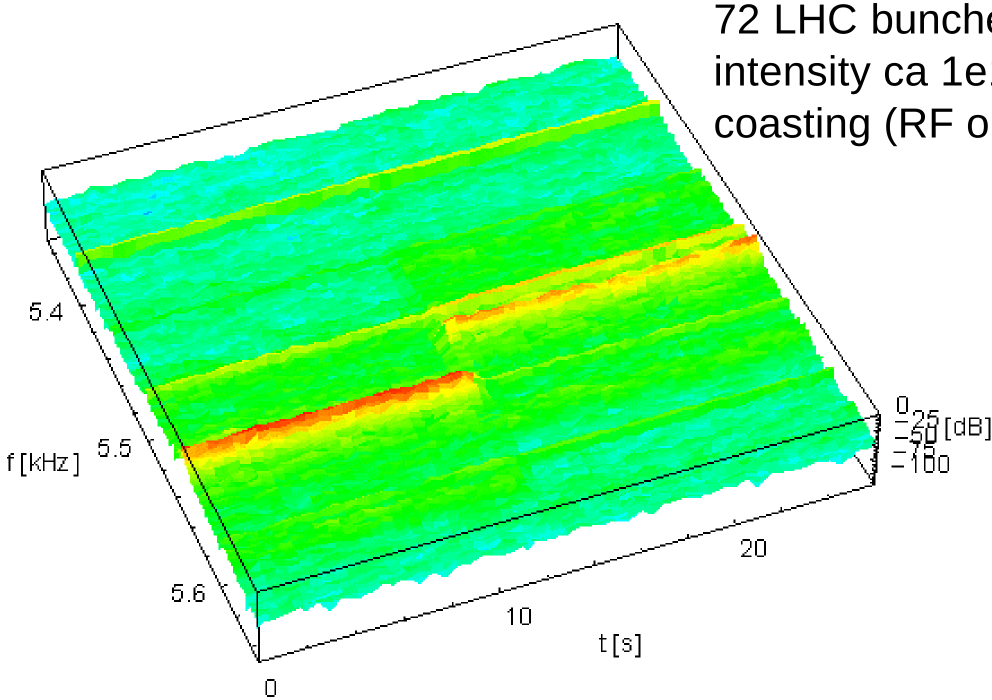


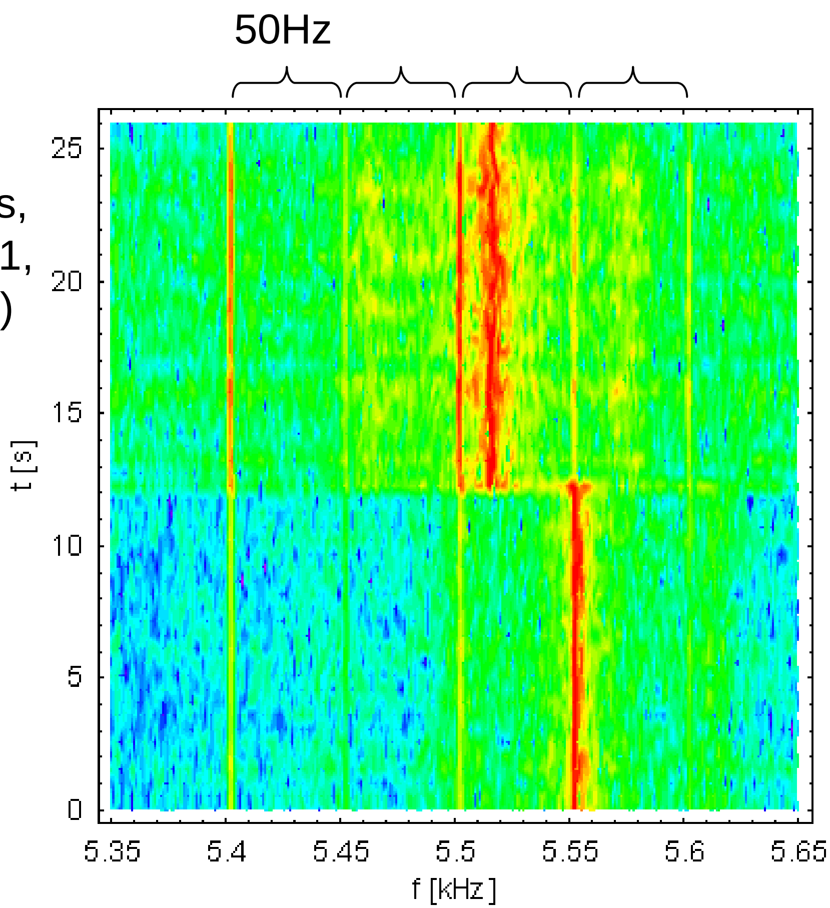
SPS BBQ Measurements – Mains Ripple in the Beam Spectrum



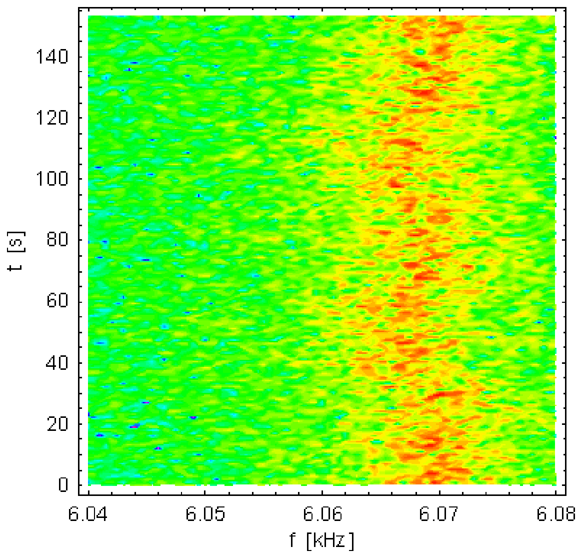
Even at 5kHz, sitting the tune on a 60Hz multiple excites the beam!

72 LHC bunches, intensity ca 1e11, coasting (RF on)

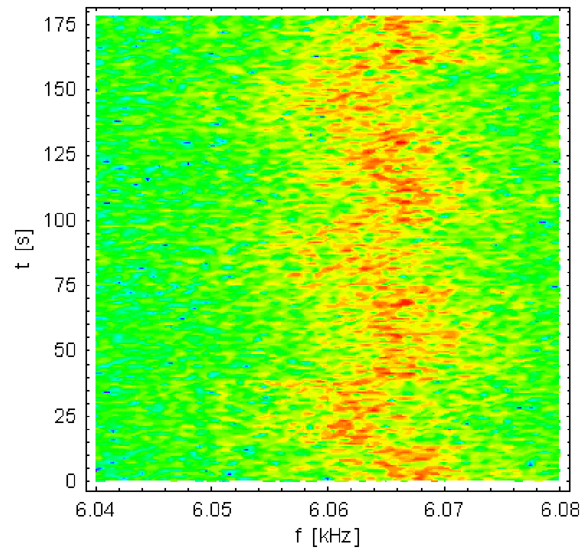




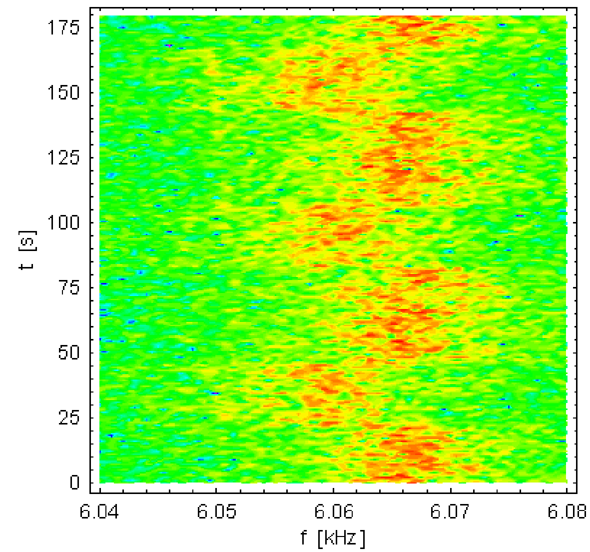
Collimator gap @ 4.86 mm



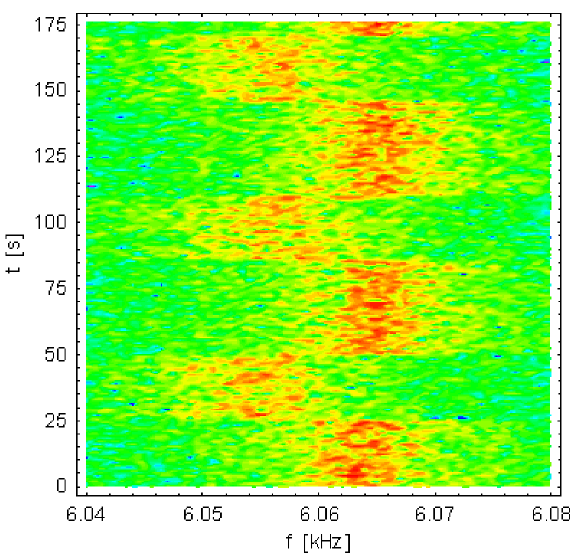
Collimator gap @ 3.86 mm



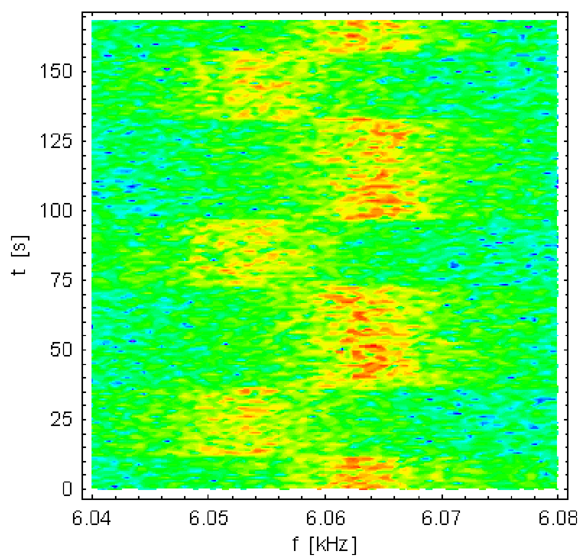
Collimator gap @ 2.86 mm



Collimator gap @ 2.26 mm

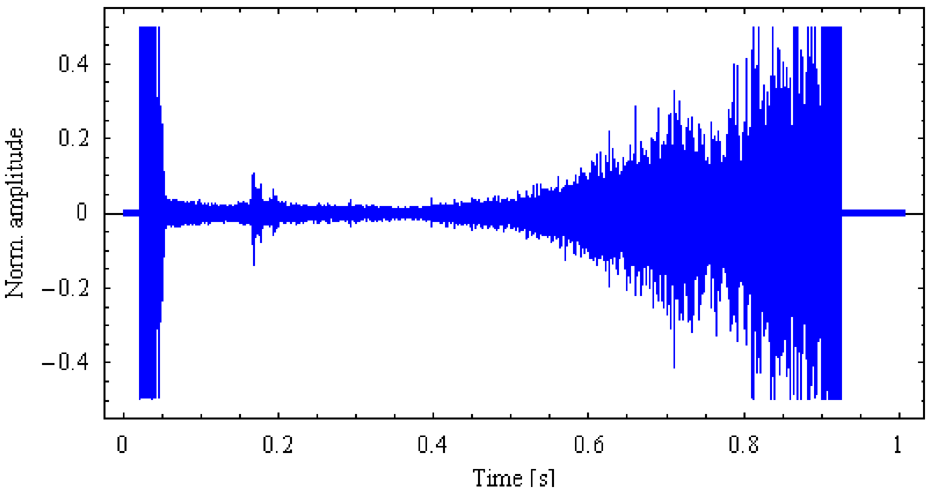


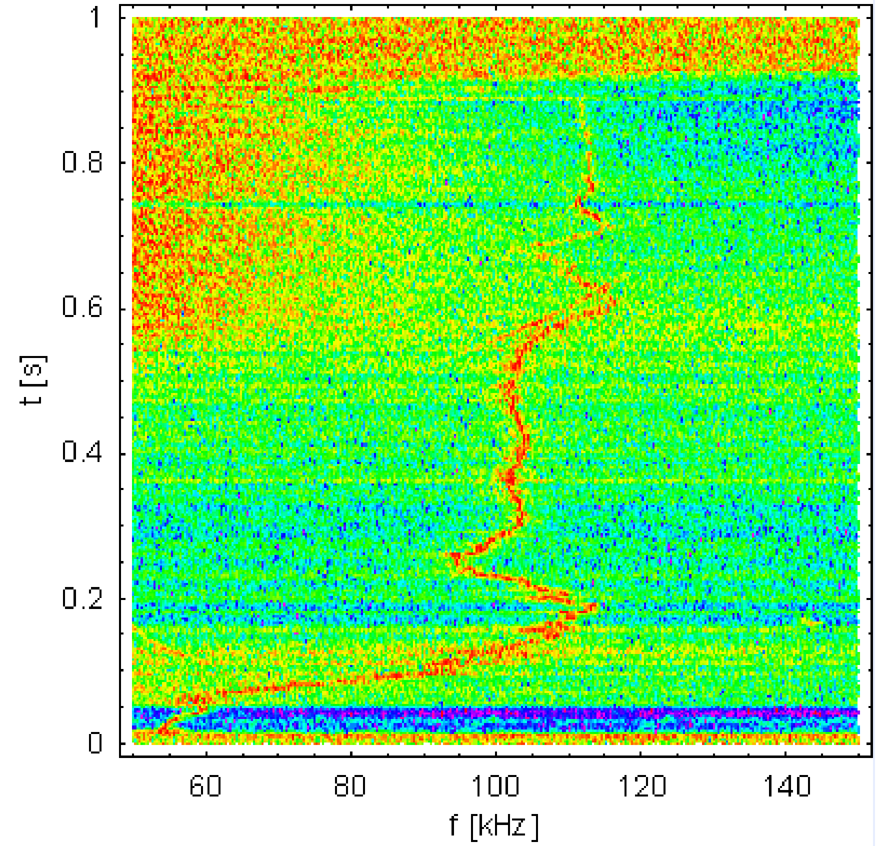
Collimator gap @ 1.96 mm

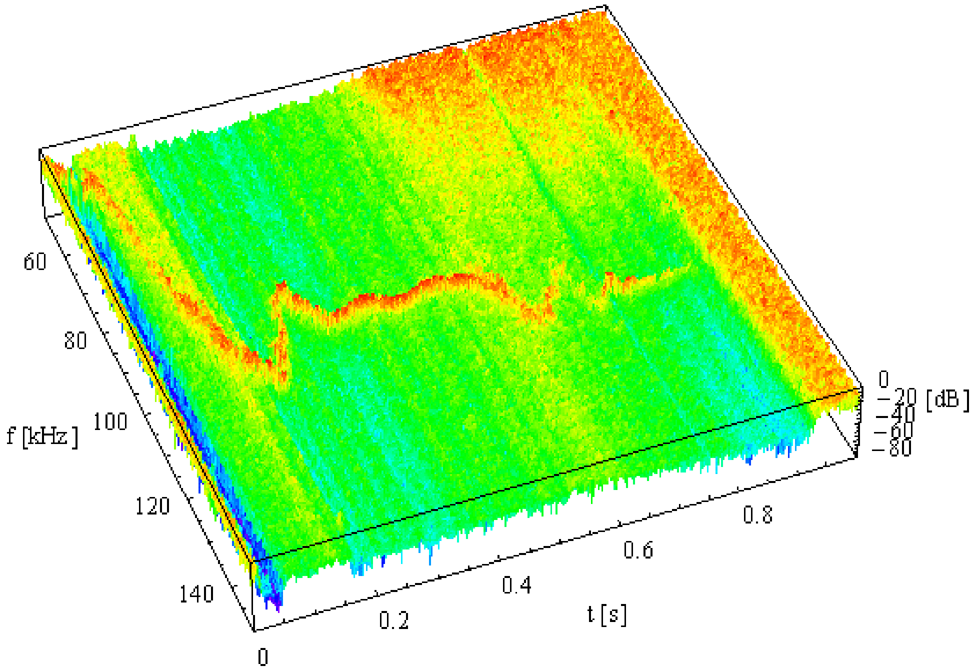


With no explicit excitation, the BBQ system is clearly able to distinguish steady state tune differences of $<10^{-3}$ for single LHC pilot bunches.

PS BBQ Measurements – AD Cycle

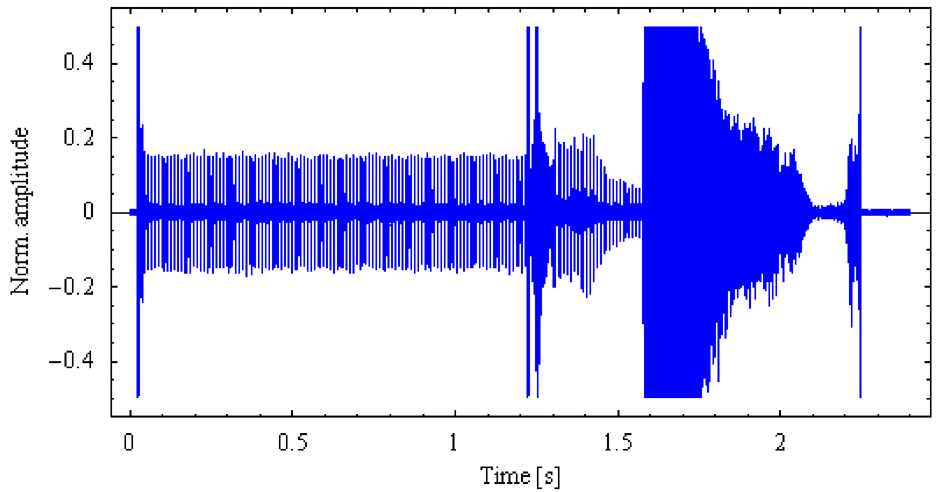


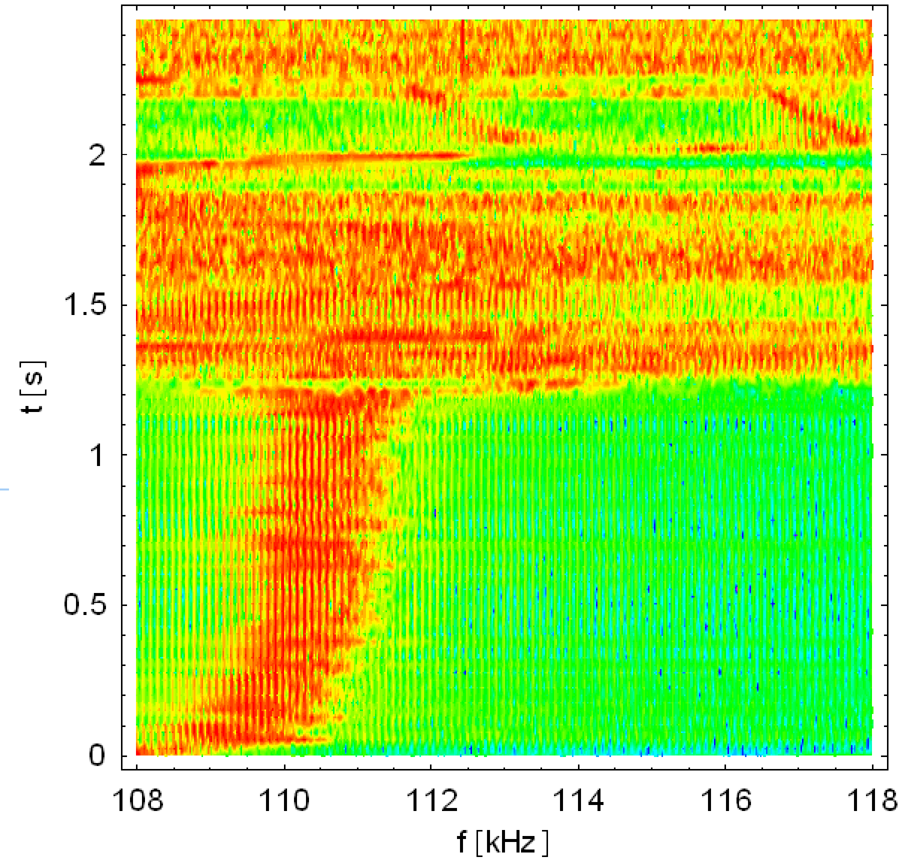


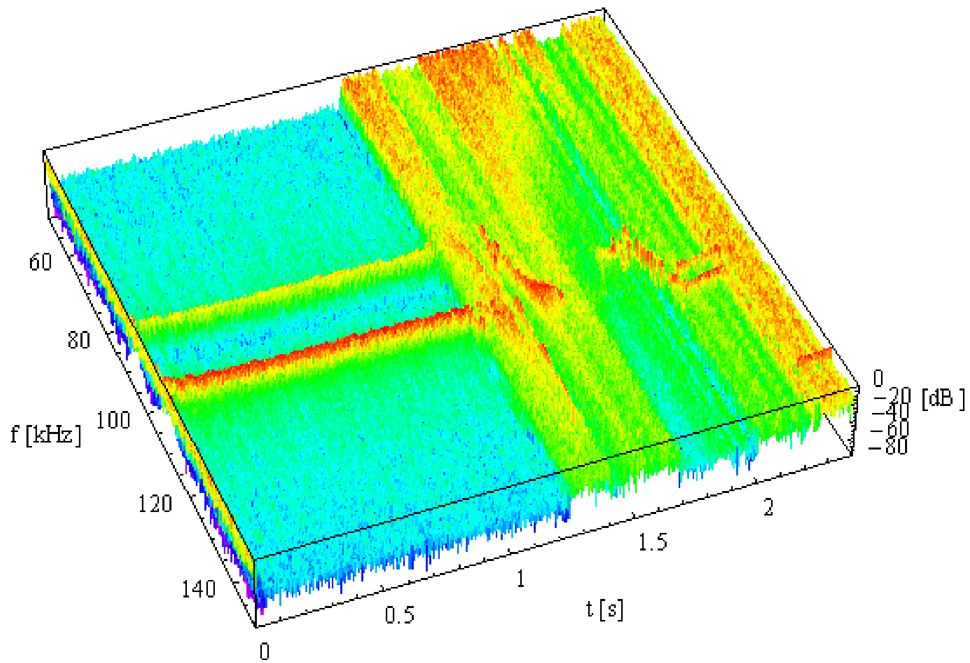


No explicit excitation

PS BBQ Measurements – LHC Cycle – Mains Ripple







Q kicker fired every 10 ms
with the minimal strength

Advantages

- Sensitivity
- Virtually impossible to saturate
- Simplicity
- No resonant PU, no movable PU, no hybrid, no mixers
- It can work with any PU
- Base-band operation guaranties the independence of the machine filling pattern
- Signal conditioning / processing in the base-band is easy (powerful components for low frequencies)
- Flattening out the beam dynamic range (small sensitivity to the bunch number)

Disadvantages

- Operation in the low frequency range
- It is sensitive to the "bunch majority"

More measurements and other plots from the presented measurements can be seen on the BBQ web site

www.cern.ch/gasior/pro/3D-BBQ/3D-BBQ.html